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Effects of MICROWAVE DEHYDRATION ON COMPONENTS OF APPLES

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This report was produced by the Western Utilization Research and Development Division, Agricultural Research Service, U.S. Department of Agriculture, Albany, Calif. 94710. Copies are available on request.

EFFECTS OF MICROWAVE DEHYDRATION ON COMPONENTS OF APPLES

F. S. Nury and D. K. Salunkhe[1]

Because microwaves heat food substances internally and rapidly, research efforts are being directed toward application of their unique performance in food processing. One possible application is dehydration of foods. Another is inactivation of enzymes or blanching prior to freezing or other processing. Several types of commercial equipment are available.

Some producers use microwave heating as a finishing step in the manufacture of potato chips. This method assures good color and crispness and also permits extension of the storage period for raw tubers through lowering of storage temperature. Ora Smith (14) and Miles J. Willard (17) discussed divergent views of this application to chips at the 17th National Potato Utilization Conference.

C. C. Huxsoll has conducted studies on dehydration of large potato dice and apple wedges in a final step. He has found it possible to reduce moisture content to a low level and to increase the porosity of products. His work on potato dice was reported at the 16th National Potato Utilization Conference (5). Studies on both potatoes and apples are scheduled for publication soon. Rockwell, Lowe, Huxsoll, and Morgan have developed equipment in which food pieces can be exposed to microwaves and also vacuum. Sudden release of the vacuum causes puffing (12).

Researches on microwave dehydration must proceed in several directions, such as efficiency of operation and achievement of practical costs. The studies reported here consider a third need--the need for knowledge of the effects of microwaves on composition and quality of the foods. In these studies, effects on color, SO_2 levels, enzyme activity, aromatic compounds, and organic acids were measured in apples.

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[1] The senior author is a member of the staff of the Western Utilization Research and Development Division, Agricultural Research Service, U.S. Department of Agriculture. Dr. Salunkhe is Professor of Food Science and Technology of Utah State University. Use of commercial names does not imply endorsement by the U.S. Department of Agriculture. Numbers in parentheses refer to literature listed at the end of this report.

Methods and Materials

Six hundred pounds of Winesap apples were obtained from a commercial distributor. In all experiments, apples were peeled, cored, and sliced into twelve wedges per apple and were divided into two lots. One lot was dipped in a 1 percent sodium bisulfite solution for 3 minutes; the other was not treated with sodium bisulfite. Each lot was subdivided into three batches which were dried by three methods; also, in another experiment, 100 pounds of commercially dried Pippin apples were dehydrated further by the three methods used for the Winesap apples.

Standard dehydration. Products dried by standard dehydration were placed on trays and dehydrated in a Proctor and Schwartz cabinet dryer at 71°C. (160°F.) with air velocity set at 500 ft./min. until moisture content was lowered to about 5 percent or less. During the 18 hours of drying of the fresh apples, the moisture content was determined periodically to obtain a drying curve (fig. 1).

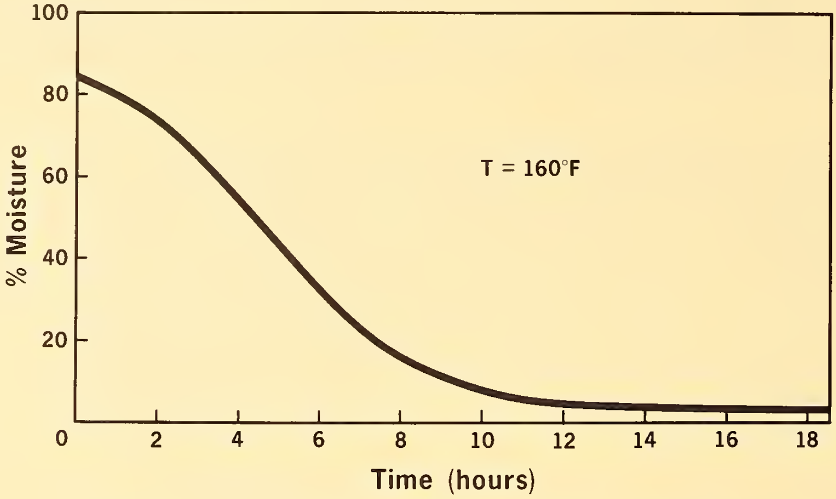

Figure 1. Standard drying curve (cabinet).

Freeze dehydration. Peeled and sliced apples with or without sulfur dioxide treatment were placed on trays and frozen in a blast of air at -34°C. (-30°F.) for 15 minutes. The frozen apple slices were then placed in a Stokes freeze dryer and dried at an average cabinet plate temperature of about 60°C. (140°F.) for 16 to 18 hours at 1 mm Hg.

Microwave dehydration. Initial experiments were conducted on peeled and sliced apples in a Radar Range Mark IV microwave oven (2450 megacycles). Preliminary evaluation with various load levels and experimental conditions indicated that production of low-moisture dried fruits directly from fresh fruit was not practical because of external and internal damage. Studies were also conducted in an experimental continuous-process microwave machine (Cryodry, 915 megacycles). In these studies the product was similarly damaged when fresh fruit was used. The damage occurred at all air-flow settings and power outputs that were tried (fig. 2).

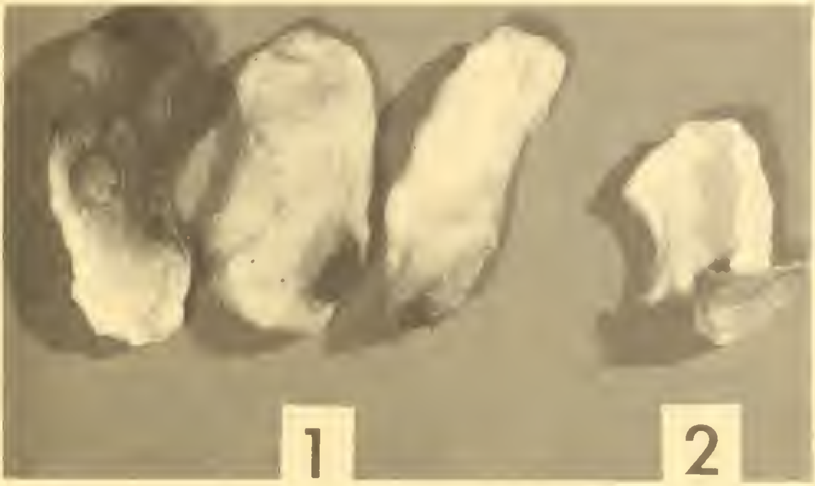

Figure 2. Effect of direct microwave radiation on fresh apple slices. (1) External burning and arcing effect. (2) Internal damage without external effect.

These problems may be attributable to the fact that the surface area available for evaporation is inadequate in size for the volume of water that is heated and vaporized. In addition irregularities in shape and density of the apple slices cause microwave energy to flow in irregular channels. As a result certain spots or sections dry and char before other areas have lost moisture sufficiently.

Microwave treatment was therefore used only for final drying of apples; that is, the fresh apples were first dehydrated in a cabinet dryer to about 16 to 18 percent and then dried down by microwave to about 5 percent moisture content. Dehydration below 5 percent moisture also tended to damage the product. To lower moisture content below 5 percent another procedure would be needed, such as vacuum.

In another experiment, commercially dried Pippin apples (approximately 21 percent moisture) were dehydrated for 1 hour in a cabinet dryer to about 16 percent moisture and subsequently dried by microwave. The product was compared with freeze-dried and dehydrated apples prepared from the same commercial lot.

The continuous process machine (Cryodry), which had a higher production rate, was used in the subsequent studies. The air-flow rate was set at 100 ft. per min. and the tunnel temperature was maintained between 194° and 203°F. (90 to 95°C.) with the microwave power source set at 0.6 amp. and 12 kv. (7.2 kilowatts). This procedure suggests only one method for the production of low-moisture dehydrated apples. It does not exclude other methods that may also produce adequate dehydrated products.

The 5-minutes drying by microwave was faster by a substantial margin than that required by standard dehydration or freeze-drying. With the latter techniques several hours were required to lower the moisture content to about the 5 percent level from an initial 16 percent. It would therefore appear quite advantageous to utilize microwave dehydration in this range of moisture content, because it provides an efficient and possibly an economical procedure.

Effects on Color, SO_2 Levels, Total Solids, Nitrogen, Crude Fiber, Enzyme Activity

Evaluation methods. Color was measured by a Hunter color and color difference meter according to the method of Lukens and Creese (6). Total solids, crude fiber, and nitrogen were determined on treated Winesap apples by AOAC Methods (1). Moisture analyses were conducted by the method described by Nury *et al*. (9).

Colorimetric analyses of sulfur dioxide, using P-rosanaline hydrochloride and formaldehyde, on the fruit water extracts (stabilized in mercuric chloride) were conducted according to the method of Nury *et al*. (7,8). Polyphenol oxidase enzyme activity was determined by the method of Ponting (10) and peroxidase activity by the method described by Dietrich and Neumann (3).

Color measurements. Color is an important criterion of quality in dehydrated fruits. Dehydrated apples should be light, and deviation from lightness to brown is usually associated with deteriorative changes. Reflectance color measurements determined by L values are closely related to the appearance of the color of the apple as seen by the naked eye and can be used conveniently for comparative evaluations. Reflectance measurements were made on Winesap apple wedges dehydrated by the three techniques. In untreated dried apple wedges, the low L value indicating darkening was reversed slightly in the terminal stages of dehydration, freeze drying, and microwave dehydration. This phenomenon may be due to tissue structural changes (puffing) induced by these techniques. Sulfur-dioxide-treated apples that were freeze-dried had a lighter color than microwave-dehydrated apples. The unsulfured microwave-treated apples were however superior in color to standard dehydrated apples and were as good as the freeze-dried samples. Commercially dried Pippin apples that were further dried by three methods showed no significant differences due to drying procedure (table 1).

Table 1.--Color reflectance measurements of dehydrated apples (L values)

Sample	L values[1]	LSD at[2] 5 percent
Fresh	74.45	2.73
Winesap-treated		
Dehydrated	70.81	
Microwave (915 megacycles)	72.71	
Freeze-dried	77.18	
Winesap-untreated		
Dehydrated	58.58	
Microwave (915 megacycles)	62.19	
Freeze-dried	60.85	
Commercially dried Pippen (sulfured)		
As received	72.94	15.36
Dehydrated	65.03	
Microwave (915 megacycles)	66.87	
Freeze-dried	66.01	

[1] Lower L values indicate poorer color.

[2] Least significant difference for average of 10 replications.

Sulfur dioxide changes. The sulfur dioxide analyses show that microwave-dehydrated apples lose sulfur dioxide content during dehydration much more rapidly than either standard-dried or freeze-dried products (table 2). Thus they would require higher initial sulfur dioxide contents if dried products with sulfur dioxide content at the "standard of the trade" levels are desired.

Compositional changes. Analysis of total solids, nitrogen and crude fiber on treated Winesap apples did not show any significant changes due to methods of dehydration (table 3).

Enzyme activity. The most important enzyme involved in browning is polyphenol oxidase, which, like other enzymes, can be denatured by heat. However, heat often imparts an undesirable flavor and cooks the product. Inactivation must be accomplished with care and minimal application of heat.

Table 2.--Sulfur dioxide content of treated apples dehydrated by different procedures

	SO_2 (p.p.m.-moisture-free basis)
Winesap	
Fresh	2980
Dehydrated (standard method)	982
Microwave-dehydrated (915 megacycles)	620
Freeze-dried	1970
Commercially dried Pippins	
As received	3490
Dehydrated	2750
Microwave-dehydrated (915 megacycles)	1530
Freeze-dried	2550

Table 3.--Analysis of SO_2-treated Winesap apples dried by different procedures

	Fresh	Dehydrated	Microwave-dehydrated	Freeze-dried
	(%)	(%)	(%)	(%)
Total solids	16.2	96.2	95.0	96.4
Nitrogen	0.02	0.16	0.13	0.14
Crude fiber	0.68	4.45	4.37	4.33

Polyphenol oxidase activity was visually measured on the untreated Winesap wedges that were dried by the three different methods. Results in figure 3 indicate little or no enzyme activity in the microwave-dried apples, followed by standard dried apples which showed little to no activity and freeze dried, which showed a higher degree of activity. Peroxidase activity based on the brown color formed by guaiacol and hydrogen peroxide, expressed as change per minute in optical density ($E_{2\ cm.}^{25°C.}$ at 420 mμ), showed the following results: Fresh apple slices gave a value of 0.031 ΔE per minute after 1-1/2 minutes whereas freeze-dried apples gave a value of only 0.005 ΔE per minute after 9 minutes. Normally, if 0.005 ΔE per minute is obtained even after 3-1/2 minutes in vegetables, the product is considered to be adequately blanched (3). In microwave-dehydrated and standard-dehydrated apples, no color was formed even after 1-1/2 hours, indicating that complete inactivation was accomplished.

Effects of Dehydration Methods on Organic Acids

The low-moisture apples prepared by various techniques were analyzed for organic acids, free amino acids and for ascorbic acid.

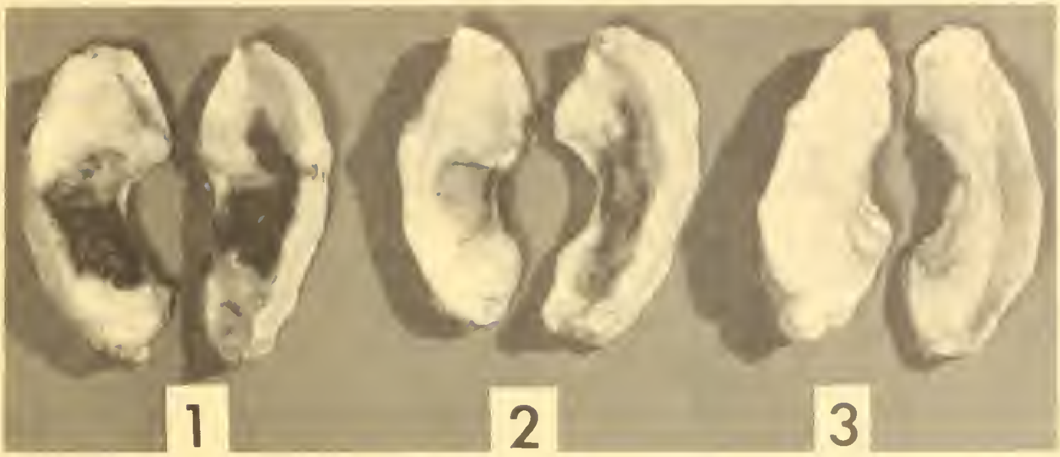

Figure 3. Untreated Winesap apples showing polyphenol oxidase activity. (1) Freeze dried, (2) standard dehydration and (3) microwave dehydration.

Organic acid determination. Organic acids were determined by the method of Bulen et al. (2), as modified by J. Guggolz (unpublished). Fifty grams of dried apple wedges were blended for 3 minutes with 300 ml. of 80 percent ethanol. The sample was poured into an Erlenmeyer flask; the flask was covered with Parafilm and the sample was allowed to stand at room temperature for 1 hour. The sample was then centrifuged at 3,000 r.p.m. for 10 minutes and the supernatant was filtered through Whatman No. 2 paper. One hundred and seventy-five milliliters of apple filtrate was then passed through an ion exchange Dowex 1 column (about 100 mesh) at the rate of 120 ml. per hour. The column was washed with 5 volumes of water (5 times volume of resin). Elution with 20 ml. of 6 N formic acid at the rate of 30 ml. per hour followed. The eluant was heated at 40°C. (104°F.) to dryness and the residue was dissolved in boiling, double-distilled water to final volume of 20 ml.

The samples were developed on the silica gel column by addition of a series of n-butyl alcohol-chloroform solvents at different ratios from a Buchler Vari-Grad gradient elution apparatus to give maximum separation. The solvents were added to the top of the separation column with a positive pressure so that there was no interruption of the flow at the top of the column. Quantities and ratios of butanol in chloroform used to load the Buchler Vari-Grad gradient elution apparatus were: 0 percent, 98.5 ml.; 2 percent, 100 ml.; 10 percent, 104 ml.; 24 percent, 112 ml.; 50 percent, 128.5 ml. (3 containers). By this method, 135 fractions were collected by a Vanguard volumetric fraction collector and the presence of acids in each peak area fraction was determined by titration with 0.0103 N sodium hydroxide with the aid of a Radiometer titrograph.

In an attempt to identify the unknown organic acids that were fractionated, fumaric, succinic, malonic, oxalic, malic, and citric acids were used as standards and separated on column and eluted by the procedures used for the unknowns.

Free amino acid determinations. Twenty grams of dried apple wedges were ground and extracted with 100 ml. of 67 percent methanol in a ground-glass-stoppered 250-ml. Erlenmeyer flask for 16 hours. The sample was filtered on Whatman No. 2 paper and the residue was re-extracted twice more with 100 ml. of 67 percent methanol for 1 hour and for 30 minutes respectively. The filtrates were combined with the original extract. The extract was evaporated to less than 20 ml. under vacuum with a rotary evaporator. The final volume of the extract was brought to 30 ml. with water. The extract was chromatographically analyzed for amino acids by an automatic recording amino acid analyzer (Phoenix Precision Instrument Company, Model K800B). Free amino acids were determined by a modification of the method of Spackman *et al*. (15). The resin column (50.5 x 0.9 cm. for acid and neutral amino acids and 11 x 0.6 cm. for basic amino acids) was packed with sulfonated styrene, 8 percent divinyl benzene copolymer cation exchange resin (particle size 25 to 31 microns). The flow rate was 30 ml. per hour of buffer and 15 ml. per hour of ninhydrin reagent. The temperature was 30°C. and the buffer pH was 5.380 for basic and 3.25 and 4.25 for acidic and neutral amino acids. Some amino acids (e.g., hydroxyproline) required a longer column (150 cm.) to give a better resolution.

Ascorbic acid. Ascorbic acid was photometrically analyzed by the method of Ruck (13).

Discussion of acid studies. In the Winesap apples dehydrated by the three different methods in this study, organic acids that were fractionated on the column and subsequently identified were small quantities of fumaric and large quantities of malic. Figure 4 shows the relative relationship of fumaric and malic acid in Winesap apples dehydrated by the different methods. Fumaric acid was found to be the highest in freeze-dried apples, followed by microwave and standard dried apples, respectively, whereas malic acid did not vary greatly in the samples dried by differing methods. It would appear that the decreased fumaric acid may indicate chemical degradation or conversions that usually can occur more rapidly in this acid; apparently in freeze drying and microwave drying, fumaric acid content remains higher than that in standard dried apples.

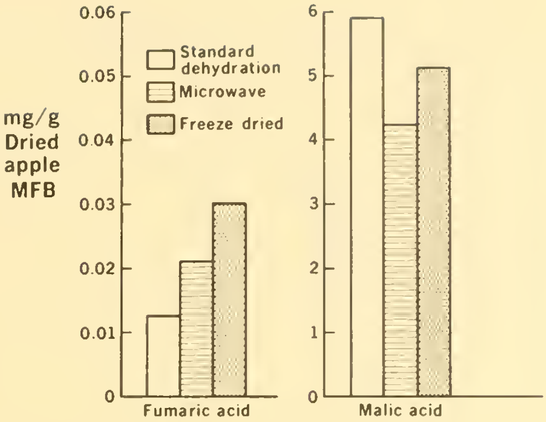

Figure 4. Organic acids in dehydrated Winesap apples.

Free amino acid analysis was conducted on sulfured Winesap apples dehydrated by the three methods (table 4). Freeze-dried apples had the highest concentrations of glutamic acid, phenylalanine, serine and aspartic acid, whereas they were the lowest in hydroxyproline, tyrosine, and glycine. The microwave-dehydrated products were high in tyrosine and hydroxyproline but contained much lower quantities of asparagine, leucine, isoleucine, methionine, valine, proline, serine, threonine, and aspartic acid, than did the standard dehydrated and freeze-dried samples. The apples dried by standard dehydration were higher in glycine, alanine, leucine, and asparagine, and lowest in β-alanine.

It is possible that the relatively lower quantities of free amino acids in microwave-dehydrated apples are due to a lesser degree of protein hydrolysis. The lesser availability of amino acids in microwave-dried fruit may be a factor in limited or delayed Maillard-type reactions which take place in browning of fruits, particularly when no sulfur dioxide is present. Consequently, microwave exposure may render the fruit more resistant to discoloration and other deleterious changes. This hypothesis possibly can be supported in part by the fact that standard dehydrated fruits, which are more readily susceptible to browning, appear to have relatively higher concentration of free amino acids.

Figure 5 presents results of ascorbic acid analyses of sulfur-dioxide-treated and untreated apple wedges dried by different methods. The loss of ascorbic acid when no sulfur dioxide was present was nearly complete, regardless of the

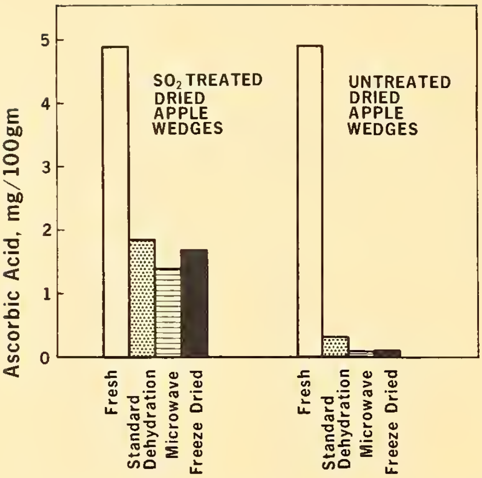

Figure 5. Ascorbic acid content of treated and untreated dehydrated Winesap apples.

method of dehydration used. However, the presence of sulfur dioxide decreased the loss of the vitamin significantly. No major differences were noted in the ascorbic acid content of the apples

Table 4.--Neutral and acidic free amino acids in sulfured Winesap apples dehydrated by the three methods (basic amino acids were not found in measurable quantities)

Amino acids	Standard dehydration	Microwave-dehydrated	Freeze-dried
	(micromoles per gram of apples x 10^{-3})		
Aspartic acid	70.7	16.3	86.8
Threonine	5.77	1.05	4.10
Serine	15.6	2.63	19.8
Glutamic acid	9.35	3.15	40.15
Proline	5.77	--	4.16
Glycine	3.64	1.05	0.88
Alanine	54.1	18.4	21.3
Valine	6.24	0.89	6.20
Methionine	0.88	(trace)	0.42
Isoleucine	5.77	1.61	6.24
Leucine	3.12	0.89	1.04
Tyrosine	19.2	21.5	1.04
Phenylalanine	4.16	3.68	8.84
Asparagine[1]	99.4	2.63	50.9
Hydroxyproline[2]	8.0	29.04	(trace)
β-Alanine	(trace)	2.1	2.1

[1] Asparagine peak may have contained glutamine as well.

[2] Traces of lysine were also found on the long basic column.

dried by the three methods, but the beneficial effect of sulfur dioxide in ascorbic acid retention during dehydration processes was markedly demonstrated.

Effect of Dehydration Method on Volatiles, Flavor, and Texture

Vapor-phase gas-liquid chromatography was conducted by the method of Teranishi and Buttery (16) on a laboratory-constructed, dual-flame chromatograph. The columns were 20 ft. long and made from 3.2 and 6.4 mm. o.d. stainless steel tubing. The tubes were filled with silicone SF-96(50) on 70 to 80 mesh Chromosorb, then coiled and aged at about 250°C. for a week. During this time nitrogen saturated with water was passed through continuously. The carrier gas which was passed through the conditioned column was nitrogen at a pressure of 40 p.s.i. The detector unit was maintained at 110° to 120°C. and the columns were placed in an air-bath oven so that temperature could be maintained constant or programed during a run.

Ten-gram samples of dried or fresh apple wedges were placed in 250-ml. flasks. The flask heads were covered with foil and stored at room temperature for 20 hours. A hypodermic needle was inserted into the flask and 10 ml. of vapor was sucked into the syringe. The syringe contents were then injected directly into the chromatograph. The peaks of volatile components were recorded automatically and their emergence times (measured in chart distance traveled) were noted. For fresh apple slices a half-hour incubation period was used prior to vapor removal.

Sensory evaluation tests. Sensory evaluation by triangle taste test for flavor was conducted by the method described by Guadagni (4). Taste panel comparisons were made of apples prepared as apple sauce.

Tissue texture evaluation. Photomicrographs were taken of the differently dehydrated apples according to the method described by Reeve and Leinbach (11) for comparison.

Results. Direct vapor analysis of sulfur-treated Winesap apple wedges dried by different methods were made in a dual-flame ionization detector. Analyses were also made on apple slices at different stages in a cabinet to determine changes taking place during dehydration (fig. 6). Vapor components of the fruit, samples of known volatiles (alcohol, aldehydes, esters, and certain other organic volatiles) were analyzed and their emergence times were recorded for comparison.

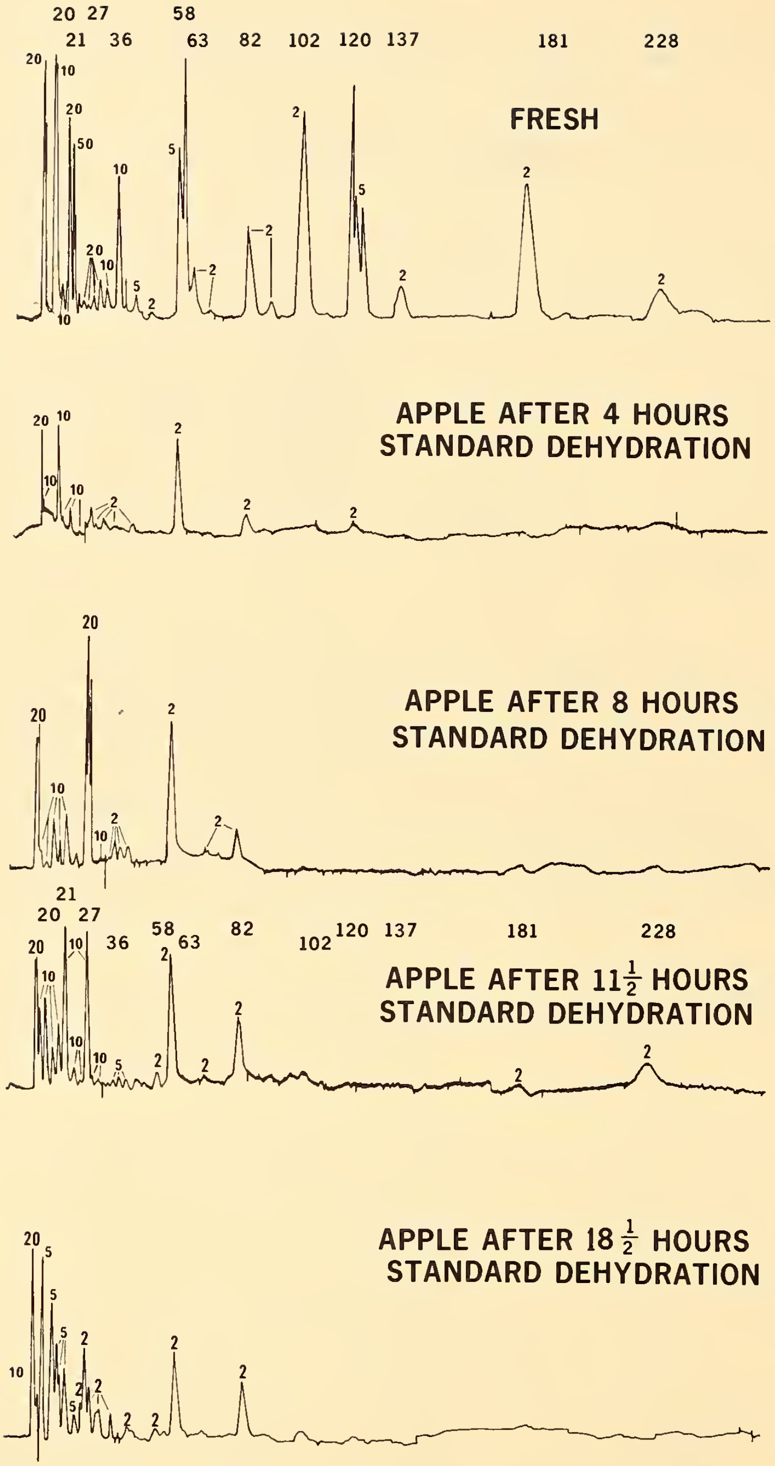

Figure 6. Gas-liquid chromatograph of SO_2 treated Winesap apples during dehydration by the standard (cabinet) method. Small numbers above peaks refer to attenuation of the recorder. Large numbers indicate millimeters from air peak reference point.

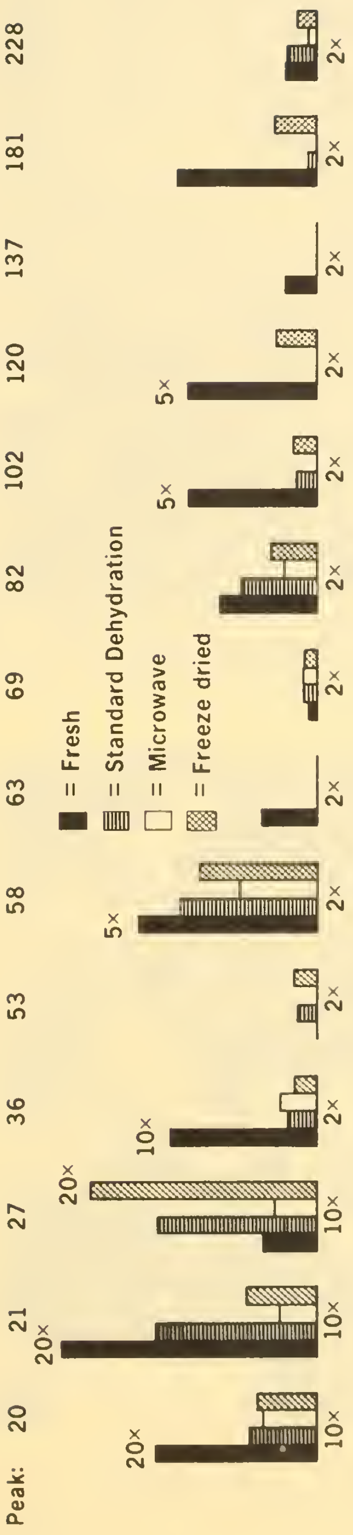

Figure 7. Comparison of major GLC peaks for SO_2 treated Winesaps dehydrated by the three methods.

Fresh apple volatiles produced higher peaks than volatiles from the corresponding fruits dried by the three methods, except for peaks 27 and 53 (fig. 7). Peaks 69 and 228 were nearly equal in all the samples. Within various methods of dehydration no major differences were noted for peaks 21, 36, 69, and possibly 228, indicating that the aroma as represented by these peaks is comparable regardless of technique of dehydration used. Peaks 63 and 137 were lost in all samples that were dehydrated. Microwave dehydration provided the highest concentration of volatiles among the dehydration methods used in peak 36, whereas the freeze-dried product gave the highest concentrations of volatiles for peaks 27, 120, and 181. Standard dehydration gave the highest concentrations for peaks 21, 58, and 82.

Taste panel evaluation of the samples prepared as sauce from Winesap freeze-dried apples were preferred by the panel of judges over apples dehydrated by the other two methods. However, no significant differences were noted by the panel when microwave-dried and standard dehydrated apples were compared. Also when commercially dehydrated Pippen apples, which were further dehydrated by the three methods from 16 to 5 percent were made into sauce and judged by the taste panel, no significant differences were noted, indicating that all methods used gave equally acceptable products.

Photomicrographic examination of Winesap apples dehydrated

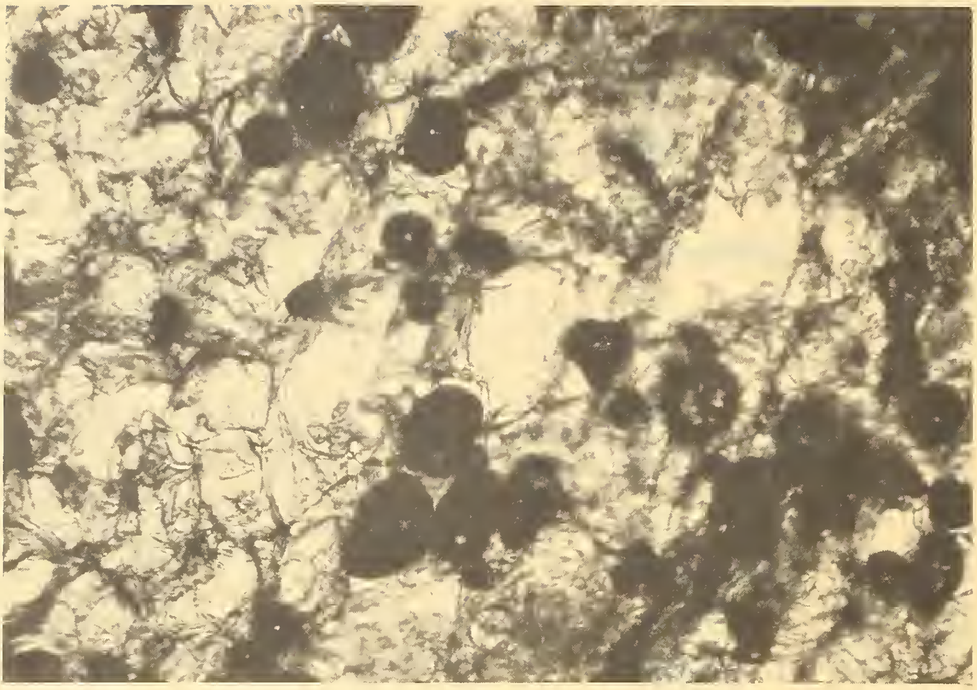

Figure 8. Photomicrograph of freeze-dried Winesap apple tissue (dry condition).

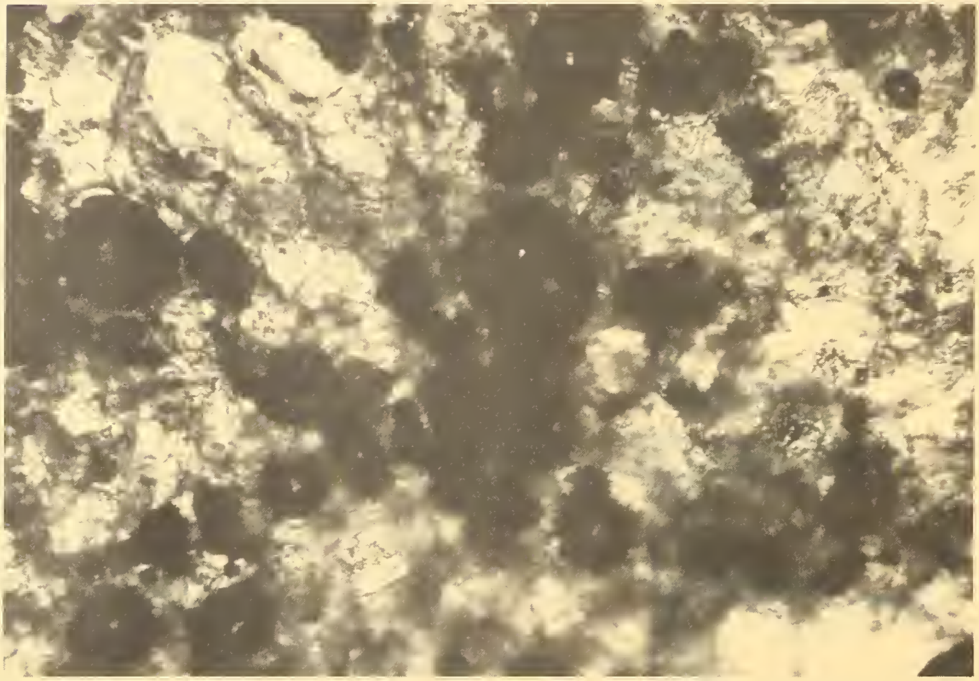

Figure 9. Photomicrograph of Winesap apple tissue dried by the standard method.

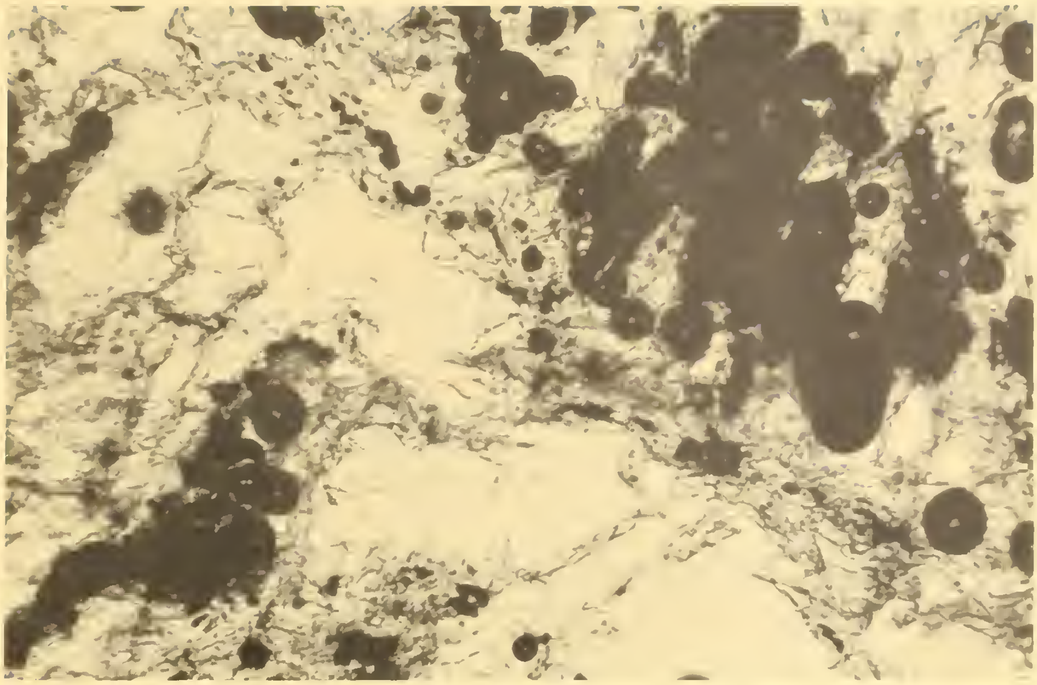

Figure 10. Photomicrograph of Winesap apple tissue dried by the microwave technique.

by different techniques (dry condition) were made for comparative studies. Photomicrographs of freeze-dried samples showed some large air-free intercellular spaces (fig. 8). Many small air bubbles were trapped within intact cells and the individual cells were shrunken but not severely collapsed. Conventionally dehydrated apples had very severely shrunken cells and few air-free intercellular spaces containing many trapped air bubbles (fig. 9), whereas microwave-dehydrated apples showed large intercellular spaces which, as in the freeze-dried product, were air-free (fig. 10). Individual intact cells were shrunken more than freeze-dried apples but not as much as standard dehydrated apples.

Thus cell damage was less in apple slices dehydrated by freeze drying and microwave procedures than by standard dehydration. Studies on rehydration indicated that freeze-dried products were most readily reconstituted, followed by microwave and standard dehydrated apples respectively.

The authors are grateful to Gene M. Deady and Jack Guggolz for analytical work and to Russell T. Prescott for advice on publication of the results.

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